The potential of the ‘Internet of Things’ to enhance inquiry in Singapore schools

Abstract

Background: The Internet of Things (IoT) is a global network of data-sensing devices which pupils can access during science or other curriculum activities.

Purpose: This article reports on a commissioned evaluation of a small-scale pilot project to explore the potential of the IoT combined with local sensors to enhance pupils’ data interpretation skills within inquiry-based approaches to primary science and secondary geography education.

Sample: The project involved 14 teachers and 196 pupils from three primary and two secondary schools in Singapore.

Design and methods: Using a mixed-method approach, the evaluation drew upon repeated video interviews with the teaching teams in each school, planning documentation and repeated pupil attitude surveys to determine the extent to which investigative and inquiry-based learning had been promoted; the contextual factors influencing effective implementation and the leadership expertise required to manage the project.

Results: The combined use of IoT and local sensors appears to have effected some pedagogic change in participant teachers and led to some pupil learning gains in procedural skills; however significant technical and pedagogic challenges – together with tensions between time allocation and curriculum coverage – limited the extent to which the approach was embedded within classroom practice.

Conclusion: This pilot project suggests strategies to meet the challenges associated with using the emergent technology of the Internet of Things to enhance inquiry-based science education.

KEYWORDS: Internet of Things, sensors, data-logging, data interpretation skills, inquiry-based learning

Introduction

The ‘Internet of Things’ (IoT) is a global network of devices in domestic, industrial, scientific and educational contexts which sense data from their environments and may be accessed and controlled online. Searchable databases of public IoT sensors such as www.thingful.net can give teachers and pupils access to data from energy use, radiation, weather, and air quality devices as well as seismographs, iBeacons, ships, aircraft and animal trackers. The subset of these connected devices located in schools has been termed the ‘Internet of School Things’, which was the focus of the *IoT@Schools* project, funded by Infocomm Development Authority of Singapore (IDA) and led by the UK-based educational technology company ScienceScope Ltd in 2015-16. Despite strong performances in international tests such as PISA and TIMSS, concerns that school pedagogy in Singapore - characterized by rote-learning and teacher-directed instruction – was not equipping pupils for the 21st Century economy led to curriculum reform in 2008, introducing inquiry-oriented approaches in a number of subject areas, including science and geography. *IoT@Schools* sought to explore the potential enhancement of pupils' skills in investigation design, data collection and analysis afforded by using IoT devices and online IoT access within inquiry-based science and geography activities. This article is based on a commissioned external evaluation of the project.

Inquiry-based learning in Science and Geography

Despite its increasingly frequent appearances in research literature and curriculum documentation, a range of meanings can be attached to the notion of an inquiry-based approach (Alfieri et al. 2011); for example inquiry-based science education (IBSE) can refer to: '(a) scientific ways of knowing (i.e., the work that scientists do), (b) a way for students to learn science, (c) an instructional approach, and (d) curriculum materials' (Furtak et al. 2012, 304). Blending meanings (b) and (c), Dai et al. (2011, 139) characterise inquiry-based learning as including the following features:

- Students actively participate in learning and demonstrate active cognitive engagement.
- Knowing (not just transmission of knowledge) is treated as … (an) inductive process through observation, reasoning (sometimes argumentation), and active experimentation…
- The teacher serves as a facilitator of knowing, arousing interest and curiosity and assisting in investigation and reasoning…

- Knowledge is treated metacognitively as constructed models of some important aspects of the world… but subject to further testing and modification…
- Classroom social climate is characterized by openness to different possibilities and support for exchanges of different opinions and arguments…
- Students take responsibility for and ownership of their own learning.

These characteristics are reflected in Singapore curriculum documentation for both science and geography:

> Inquiry-based learning (in science) may be characterised by the degree of responsibility students have in posing and responding to questions, designing investigations, and evaluating and communicating their learning… (MoE 2007).
>
> An inquiry approach to the teaching and learning of Geography is a… move away from the mere memorisation of information to the comprehension, extraction and application of information from a variety of sources to construct new knowledge and understanding. (MoE 2014)

The apparent similarity between scientific and geographical approaches to inquiry in the literature is perhaps surprising and is noted by Kidman & Casinader (2017: 114), who draw attention to the shared process of: ‘conversion of ‘raw’ data from primary sources (and blending this with secondary source data, if and when necessary) so that it is usable for the ensuing analysis and communicating...’ Duschl (2008) identifies three distinct domains within inquiry-based learning – requiring a balance between conceptual, epistemic, and social learning goals – to which Furtak et al (2012) have added a fourth ‘procedural’ domain, which requires significant guidance from teachers to enable pupils to structure and sequence their investigations.

Much of the criticism of inquiry-based approaches has centred around this issue of teacher guidance. Whilst Kirschner et al (2006) argue that inquiry-based methods are unlikely to be effective because they ignore the limitations of pupils' working memory and Alfieri et al. (2011) found that inquiry-based methods with minimal or no guidance are less effective than transmissive approaches, Hmelo-Silver et al (2007) claim that teacher 'scaffolding' in the domains above transforms inquiry into a highly effective pedagogy. The level of teacher support may be viewed as a continuum from teacher-led to student-led (Furtak et al 2012), including 'structured', 'guided', 'open' and 'explanation-driven' approaches (Sandoval & Reiser 2004), involving 'hard' (pre-task) and 'soft' (in-task as required) scaffolds (Saye & Brush 2002). Where appropriate teacher guidance is provided – regardless of type (Lazonder and Harmsen 2016) - there is evidence internationally that inquiry-based approaches increase student learning (e.g. Taraban et al. 2007, Schroeder et al. 2007). In science, a combination of procedural, epistemic, and social activities undertaken as part of an inquiry-based approach typically achieves effect sizes of around 0.5 by comparison with transmission modes of teaching (Furtak et al. 2012; Wilson et al. 2010; Geier et al. 2008). In Singapore, Fernandez (2017) found that secondary students in an *Authentic Inquiry-Based Instruction (AIBI)* experimental group demonstrated significant gains in conceptual understanding of thermal physics and student self-efficacy by comparison with a control, whilst Chang (2012) found that pupils using geographical inquiry approaches were more likely to translate their knowledge, skills and values into action than those taught through transmission methods.

Much attention has been given to the development of pupil inquiry skills; for example Piekny & Maehler (2013) report that the ability to formulate hypotheses based on prior beliefs gradually develops over the primary years, whilst investigation of the relationship between variables that clearly covary can be planned by many pupils by the age of 10 (Kanari &

Millar 2004), although the skills to interpret data exhibiting ‘imperfect covariation’ do not develop until later (Koerber et al. 2011; Piekny et al. 2014). There is some evidence that technology-enhanced learning can support the development of these skills; for example Daner et al. (2016) found that the combination of IBSE with mobile technologies improved test achievement and activity performance in and out of the classroom, whilst the pedagogic deconstructing and reconstructing process involved in ‘mobilizing’ the primary science curriculum is claimed to support and enhance pupil inquiry (Zhang et al. 2010). The use of geographic information systems (GIS) through an inquiry approach was observed by Favier and van der Schee (2012) to promote ‘deeper’ geographic learning than a control group. The development of ‘online virtual laboratories’ (Cornell 2015) - whereby pupils can undertake simulated scientific or geographical inquiry at a distance – have been claimed by D’Angelo et al. (2014) to have an advantage in achievement over non-simulation instruction.

The particular affordances of sensor technology to support the development of pupils’ data interpretation skills is well deocumented (e.g. Newton 2000; Seah et al. 2005; Tan et al. 2006; Dixon 2008). The use of sensors connected to data-loggers to collect and graph data automatically can free pupil time to ‘focus on developing conceptual understanding’ (Webb 2005, 728, Barton 1997, Rogers and Wild 1996). The addition of online secondary data sources from the IoT to compare with those from local sensors can both improve the validity and reliability of pupils’ analysis and enhance their ‘data literacy’ by selecting which sources to include and which to disregard as spurious or not relevant to their inquiry (Chatterjea et al. 2008), whilst Warwick & Siraj-Blatchford (2006) found that comparing experimental data pupils have collected themselves with other sources (e.g. online) can enhance their motivation to provide explanations. The *DISTANCE* (Demonstrating the Internet of School Things - A National Collaborative Experience) project (Joyce et al. 2014) found that schools were willing to adopt IoT technology ‘within certain bounds’ and recognised the potential of the IoT for enhancing pupils’ data literacy and inquiry skills, however there is no evidence to date for the efficacy of combining IoT access with hands-on data-logging to motivate an investigative approach to either science or geography activities. This became the focus of our first research question:

> RQ1: How does learning with data and sensors encourage investigative and inquiry-based learning in Science and Geography in Singapore?

Whilst curriculum designers may recognise the importance of inquiry, its effective implementation in the classroom depends on a wide range of ‘incentives or disincentives the school and social environments provide for particular ways of teaching’ (Dai et al. 2011, 139). Contextual factors affecting the uptake of both inquiry-based and technology-enhanced approaches may include the pressure of high-stakes tests, content coverage, class size, parental attitudes, and the availability of professional development, facilities, resources and supporting infrastructure. Gislason (2010) has proposed a model for an enabling school environment for such initiatives, comprising four components: staff culture, student culture, ‘organisation’ - which comprised aspects such as timetabling and curriculum - and ‘ecology’, which comprised physical and technological resources. This model has yet to be tested in the introduction of inquiry-based approaches to science and geography using sensor technology and the IoT, which leads to our second research question:

> RQ2: In what contexts is the IoT beneficial to encourage investigative and inquiry based learning in Science and Geography in Singapore?

Two particular aspects of the school context emerge from the literature as potentially significant to the successful uptake of technology-enhanced inquiry-based approaches:

teacher expertise and school leadership. Purnell and Harrison (2011) report teachers’ general lack of expertise in elaborating and implementing inquiry in their lessons, whilst more specific weaknesses have been observed in relation to providing helpful guidance to pupils on the formulation of a research question (Zion et al. 2007) and the design of an investigation (Yoon et al. 2012). van Uum et al (2017) point towards the need for teacher support for particular domains within Duschl’s inquiry model (2008 – see above) – for example the need to address the conceptual domain in the conclusion phase – which requires specialist expertise. For teachers to be effective designers of technology-enhanced learning, McKenny et al. (2015, 190) have proposed that they need the following integrated knowledge:

- Know-what: teachers’ fundamental knowledge base
- Know-why: teachers’ productive beliefs, including articulated principles and (sometimes unarticulated) experience-based wisdom
- Know-how: teachers’ repertoire for action, including intuitive (embodied in skill) knowledge
- Know-when: teachers’ tacit and reflective abilities to judge which ideas and processes make the most sense under certain circumstances, at certain points in time…
- Know-who: teachers’ awareness for consulting relevant expertise
- Know-where: teachers’ understanding of design work in the local and broader system contexts.

Such expertise can only be acquired through professional development, which relies on the support of institutional leadership (Dai et al. 2011). It is also incumbent on the school leadership team to make time and space available for the many different pieces of collaborative planning required (Woolner et al 2014). There is evidence from a previous study of Singapore school leaders seeking to bring ICT innovation to the curriculum and pedagogy (Reyes 2015) that their roles have changed from leading a team of teachers who have been deliverers of knowledge towards leading a team of teacher facilitators. The need to observe whether such a shift in leadership approach takes place within schools seeking to integrate the use of IoT technologies and to support the development of appropriate teacher expertise leads to our third research question:

> RQ3: What leadership and expertise can help accelerate investigative and inquiry-based learning in Science and Geography using the IoT?

Methods

IoT@Schools worked with three secondary geography departments and two primary schools in Singapore through the following phases:

- installation and activation of some baseline IoT data-logging technology (weather station, generic logging kit with a range of sensors) linked to the *DISTANCE* website (www.iotschools.org.uk) and www.thingful.net in participating schools;
- participatory design activity with teachers and pupils from participating schools to identify how the IoT can best be used with the primary science and secondary geography curricula in Singapore;
- video conference ‘surgeries’ with lead teachers involved in the *DISTANCE* project to support the development of inquiry activities using data-loggers and online IoT sensor data;
- following the implementation of activities and cross-school data sharing, a workshop that explored cooperation and collaboration between schools, to gather and document good practices and implementation considerations for future deployments.

The authors were commissioned by IDA to undertake an independent evaluation of the impact of the project. A mixed-method research method was adopted due to its potential to ‘generate a more enriched understanding of the problem under investigation…’ by ‘… coming at things differently’ (Hesse-Biber and Johnson, 2013, p.103). As these data were collected for IDA from classroom practitioners and pupils, the choice was also cognisant of pragmatic issues leading to a ‘move away from theoretically-driven research to research which meets policymakers’ and practitioners’ needs’ (Östlund *et* al., 2011, p.370). To this end, and to enhance triangulation of findings (Archibald, 2016; Hong and Espelage, 2012), the following data were collected: Skype interviews with participant teachers and school principals; online observations of participatory design activities and surgeries between Singapore and UK teachers; pupil attitudinal surveys and analysis of teacher planning before and during the project. Table 1 sets out the relationship between these data sources and the research questions.

Table 1: Data sources used to answer research questions

Research question (evaluation criterion)	**Data source**
1. How does learning with data and sensors encourage investigative and inquiry based learning in Science and Geography in Singapore?	• Desk-based evaluation of pre- and in-project learning plans and resources from the 5 project schools to compare the difference in inquiry-based content as an indication of the extent to which students were encouraged to investigate. • Online student attitudinal survey (n=196) pre- and post-project to evaluate changes in perceived self-efficacy in inquiry-based learning (appendix 1).
2. In what contexts is the IoT beneficial to encourage investigative and inquiry based learning in Science and Geography in Singapore?	• Semi-structured focus-group interviews with groups of participant teachers (n=14) via Skype, before and after the project to ask about the contextual factors they perceived as central to encouraging inquiry-based learning (appendix 2).
3. What leadership and expertise can help accelerate investigative and inquiry-based learning in Science and Geography using the IoT?	• Semi-structured focus-group interviews with groups of participant teachers (see above) to ask about their perceptions of leadership factors and their own/ students’ expertise • Semi-Structured interviews with senior managers in project schools at the end of the project to ask about their perceptions of leadership factors and their teachers’ expertise (appendix 3).

Analysis of the quantitative data employed *Qualtrics* for online survey data, summarised in quantitative stacked bar-charts. Qualitative data were analysed using an inductive iterative process of open coding using *nVivo*. This process began with no preconceived codes (Morse et al., 2009) and involved thematic content analysis which was ‘comprehensive … [and] … uses the actual data itself to derive the structure of analysis’ (Burnard et al., 2008, p.429). This process involved identifying ‘recurring themes, patterns, or concepts and then describing and interpreting those categories’ (Nassaji, 2015, p.130), hence moving from broad initial codes which were refined to the final focused codes reported below.

Sample

143 primary school students aged 8-11 and 53 secondary school students aged 15-16 participated in the study, working with14 teachers – three from each school with the exception of S3 which ran the project on a considerably smaller scale involving two teachers and seven students. All five schools were chosen as government-run, English medium schools following the Ministry of Education curriculum from different areas of Singapore who expressed an interest in developing inquiry-based learning through information technology. P1 is a primary school in the East of Singapore with 322 students, 94 of whom participated from three age groups between 8 and 11, each of which had its own teacher. Primary school P2 in central Singapore involved 49 students aged 10-11 working with three teachers. S1 was a relatively small secondary school (around 500 students) in the North of Singapore, with 22 student participants. S2 is larger (1200 students) also in North Singapore, with 24 participants, whilst S3 is a former Chinese medium school with around 500 students due to merge with another secondary school in 2019.

Results

How learning with data and sensors encourages investigative and inquiry based learning

In all five schools, teachers and principals reported a shift towards more inquiry-focused approaches in science and geography, however the extent to which this is evidenced in teachers' plans varies considerably. Analysis of the plans submitted to the project online *Huddle* forum suggests a development of teacher confidence in allowing pupils to take decisions during inquiry-based activities and in providing relevant opportunities for the collection of data and comparison with IoT sources. For example, an uploaded worksheet from school P1 requires students to:

- Describe the pattern of temperature change over a 24-hour period:
- Explain the pattern/s detected:
- Compare data with (sensors in other location) over the same 24-hour period

This indicates a focus on data interpretation skills within an overall inquiry-based approach to science teaching in marked contrast to the prescriptive lesson plans submitted prior to the project. Specific mention was made of the development of particular inquiry skills:

> Some key elements of the project allow the students to predict, hypothesize, observe, test and draw conclusions. These are all elements of an investigative approach. (Teacher, School P1)

The availability of 'real-time', reliable data available from the school-based sensors and via the IoT was seen as a distinctive feature of the project which teachers reported as motivating students towards investigation:

> The children could see where exactly the data are being collected from and could relate to their environment better. Another highlight was the children being able to access the data anytime they want. (Teacher, School P1)

The Principal of School P2 expressed satisfaction (and some surprise) at the extent to which pupils were able to reason with data as part of the project activities and stated that ‘Seeing that the children are actually able to utilise the data, to work on it, and come out with assumptions and proposals for the teachers.’ (Principal, School P2)

Teachers in school P2 claimed to be already using inquiry-based approaches to science, but acknowledged that the ability to collect data over longer time-scales added an extra dimension to students’ inquiries. This also enabled teachers to select analysis periods which would show greater changes in the quantities being measured, ‘but these devices managed to further enhance our investigative learning. Students can collect data over a period of time, which makes more sense.’ (Teacher, School P2)

There were several references to enhanced analysis skills, which some teachers linked to the involvement of students in setting up the investigations and positioning the sensors, so that the resulting data were more meaningful for them. For example, ‘in the activities where pupils could see the different temperature and light levels they were able to draw conclusions from it, which was useful for them.’ (Teacher, School P2)

For the secondary geography departments, the engagement of pupils in the process of planning an inquiry and deciding upon the positioning of sensors and time-periods for data collection served to increase their procedural understanding in an authentic context. The benefits were that ‘it was doing the whole investigation cycle: Hypothesis, forming the theory, checking whether their theory was right. It was authentic (Teacher, School S1)

The process was also felt to deepen pupils’ conceptual understanding of the geographical issues encountered and develop their thinking skills:

> There was a good outcome, which is to allow students to engage in deeper learning. It allowed them to think a bit deeper in areas of weather and climate. There were vast amounts of data which allows them to do analysis and helps them to think better. (Teacher, School S2)

However, some secondary teachers felt that the availability of large amounts of data through the *IoT@schools* project had been potentially counterproductive, as pupils’ data handling and analysis skills were not sufficiently developed to make the best use of what was available. This is summed up by one teacher thus:

> They enjoyed the process, understanding, developing and interpreting of data. But sometimes they are lost because there is too much data. They didn’t know how to structure and represent the data. Past traditional methods yield very little data, but now suddenly they have to deal with a lot (Teacher, School S3).

The format in which climate data were available from some IoT sensors was seen as problematic, leading to technical issues in conversion and a loss of focus on interpretation. For example:

> The students didn’t really know how to download the data from the website itself. When the data was downloaded it was on Word document. They weren’t sure how to transfer the temperature and time data. They had to manually copy over the data and do their graphs, which took a lot of time. The copying process also meant they made some mistakes when copying (Teacher, School S3).

This revealed the need for teachers to spend time helping pupils convert, inspect and compare different sources of data in order to extract the relevant information. Once this pedagogic intervention had been put in place, there was evidence of development in pupils’ data management skills, such as

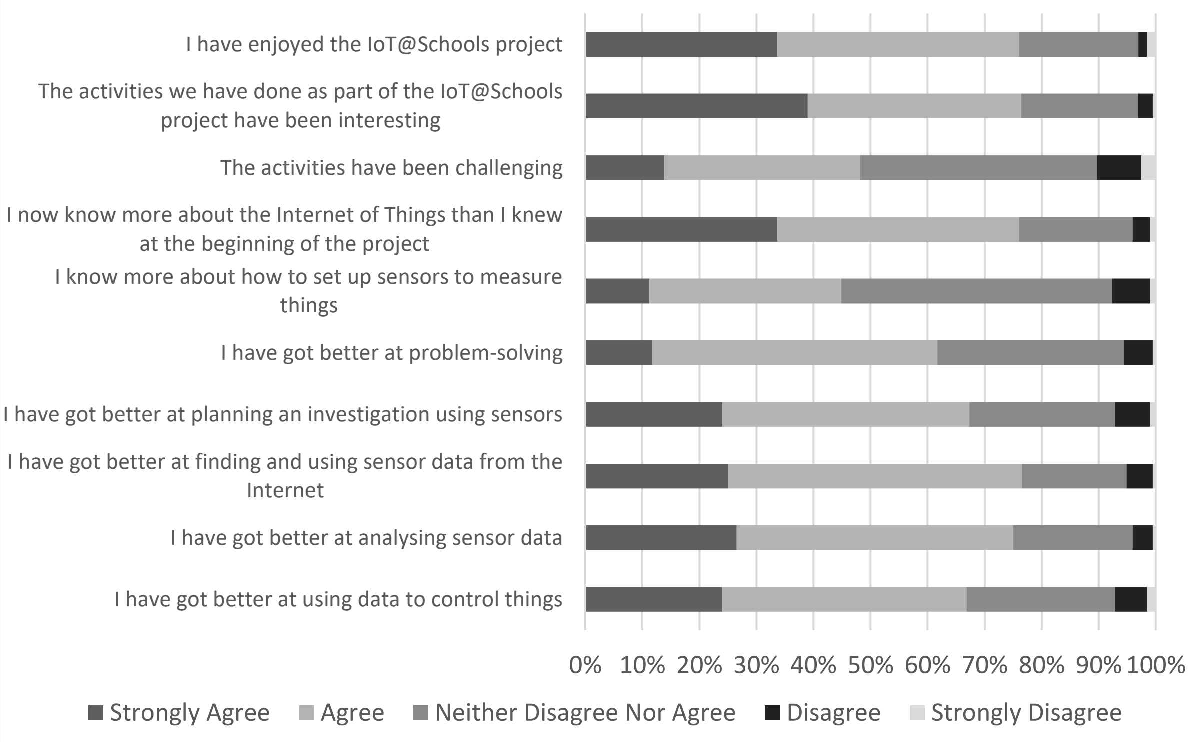
> They learnt how to select the type of data needed. They are better at narrowing down to the information required, learning what are they types of data representation they can use, and how can they actually use the data as evidence to prove their hypothesis. They learnt more on how to do this, but they have to learn more to grasp all the skills we want them to learn (Teacher, School S3).

Overall, teachers from the secondary departments reported a significant shift in their pupils’ perceptions of geographical inquiry typified by one teacher as:

> They realise that there is no right or wrong answer. They are so used to model answers given. But now they question and look at evidence to prove their hypothesis. They realise that they cannot be rigid, some things changes and in geography a lot of things are varied. Evidence is something that they can use to prove their conclusions (Teacher, School S2).

Teachers’ perceptions in interviews are supported by data from the pupil online attitudinal surveys undertaken before and after the project (n=196), in which they report improvements in investigation planning, extracting data from sensors and the internet, and analysis skills. As can be seen from the aggregated student end-of project evaluation data (Figure 1), over 60% feel that they have improved their planning of investigations together with their access, use and analysis of data, all of which are key elements of inquiry in both science and geography. A particularly strong response was given to the use of online data, with over 80% agreeing that they were now more confident in retrieval and incorporation of a wider range of remote data in their investigations. Although such self-reporting does not constitute strong evidence on its own, it is corroborated by observations of pupils during Skype-mediated ideation activities, where they were seen to advance a number of creative and relevant proposals for sensor siting and choice of data sources for analysis.

Figure 1: student end-of-project evaluations - all schools (n=196)



However, from the online student attitudinal survey completed pre- and post-project, there appear to have been some changes in the ways that primary students perceive their school science before (figure 2) and after (figure 3) the IoT@Schools project. Six statements (add here) show 100% positive responses (Strongly Agree [SA] and Agree [A]) in the pre-project survey (figure2) and four of these remain in the post-project (figure 3), with ‘I find things out in science’ and ‘I know what the teacher expect of me’ dropping only slightly. In fact, there was a slight decline in many responses in the proportions of students reporting agreement, though this may be unrelated to the project. Even questions relating to the specific use of technology (90% declining to 89%) and collection of data (97% declining to 86%) appear to show no positive impact from the IoT@Schools projected on pupil attitudes.

Figure 2: primary students' pre-project responses to statements about science

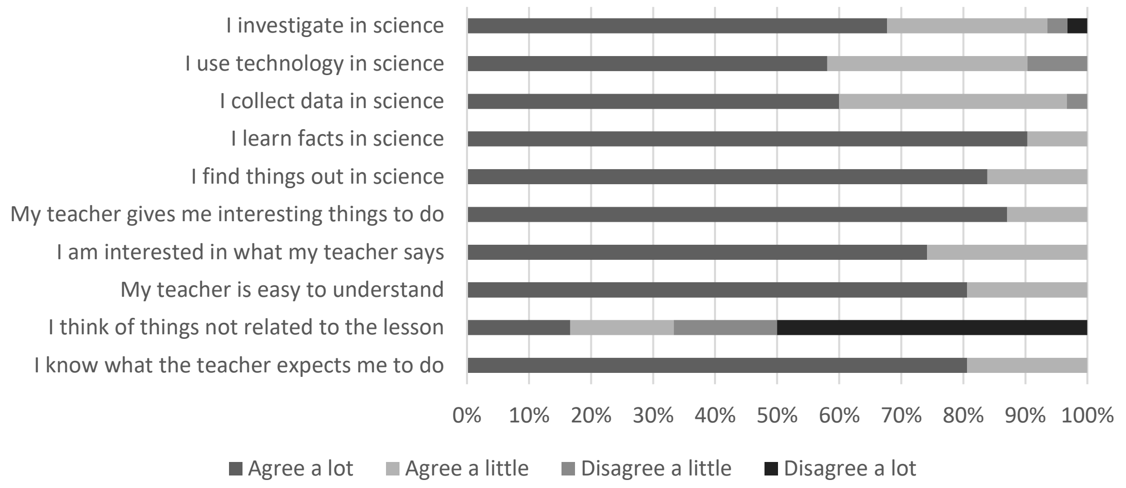
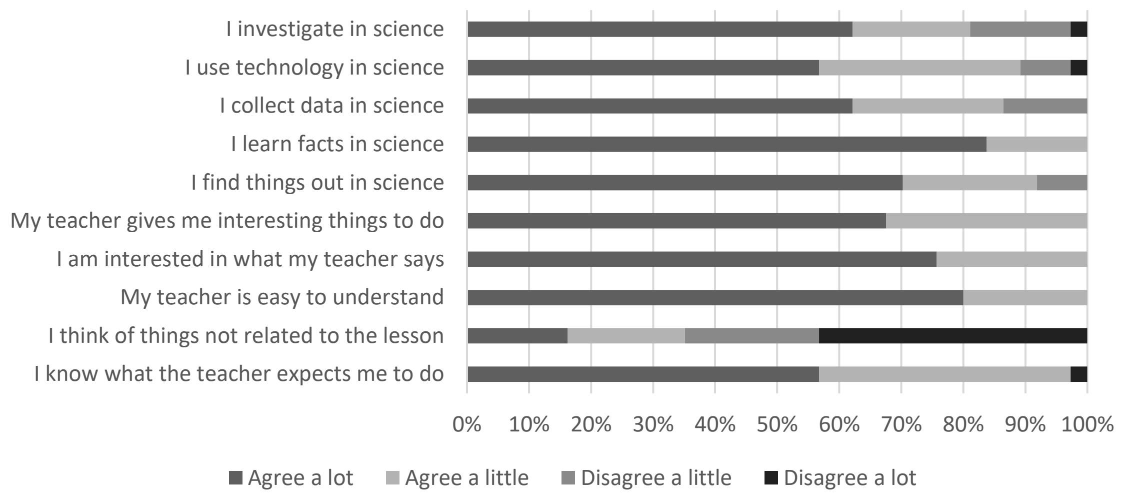


Figure 3: primary students' post-project responses to statements about science



The trend of more negative responses is even more marked in the secondary pupils’ responses before (figure 4) and after (figure 5) the project, although the baseline pre-project was lower. Only two item was 100% (SA and A) prior to the project, (“I learn facts in geography’ and ‘I know what the teacher expects me to do’ – figure 4) and none remined in the post-projects responses (figure 5). Nearly all statements showed a slight dip, although none were more than 10% points.

Figure 4: Secondary students' pre-project responses to statements about geography

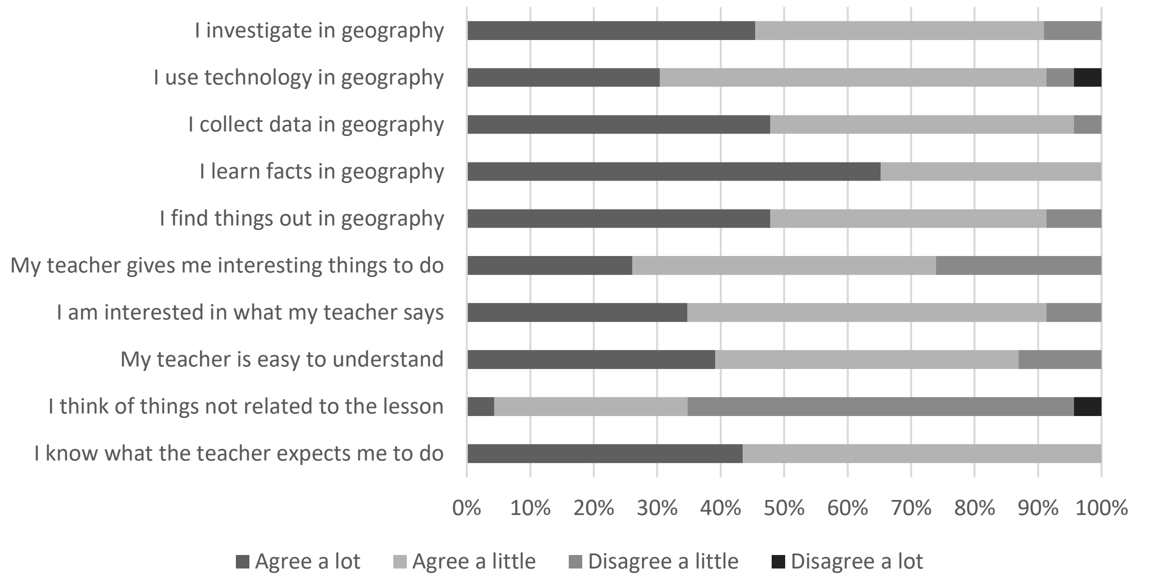
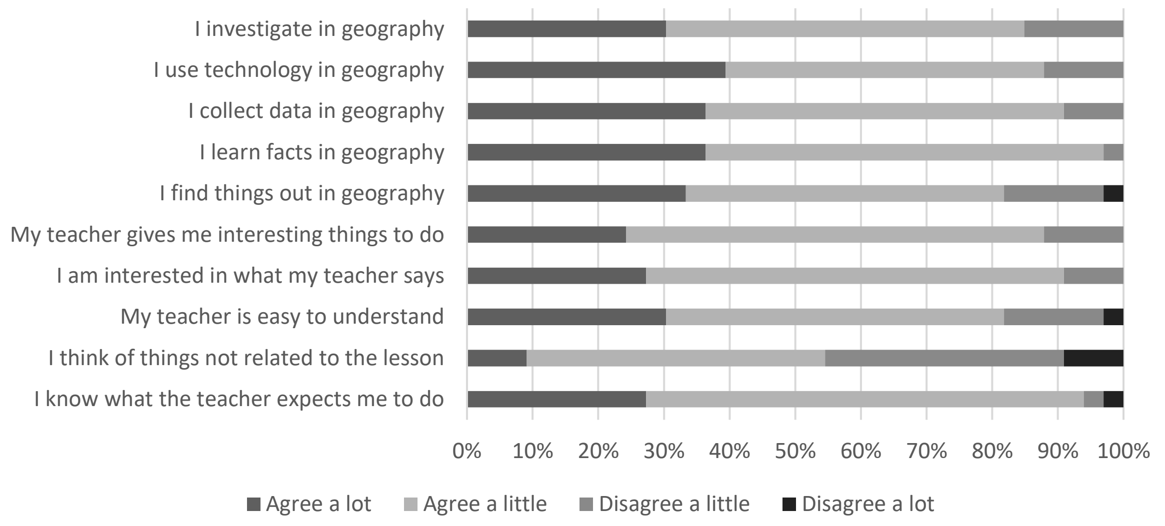


Figure 5: Secondary students' post-project responses to statements about geography



Despite the apparent limited impact of the project reported in the secondary pupil survey data, when asked to describe ‘my best geography lesson’ nine made specific reference to work undertaken during the IoT@schools project:

> My best geography lesson was when we got to… look at and read the readings from the two dataloggers placed over at the room and outside the windows to carry out our project (secondary student - 6 similar comments)
>
> When we went to do the geography fieldwork where we are require to collect data by ourselves (secondary student)
>
> In addition, we went to websites to get the temperature, relative humidity and light intensity (secondary student)
>
> We learnt lots of information like gathering and analysing datas, weather and global warning etc. (secondary student)

Contexts in which IoT is best used to encourage investigative and inquiry-based learning

Findings related to RQ2 have been grouped under three contextual factors: group size; robust technical infrastructure; and carefully-planned time allocation.

Group Size

For School P1, the choice of group size and particular students to be involved was carefully considered by school leadership as being crucial to the success of the project:

> We also looked at engaging different target groups of students to be involved in such projects. In our case we also targeted our Eco-club kids; for this group their projects were more specific. We could afford to stretch them a little more. (Vice-Principal, School P1)

Whilst such a selective approach would seem to be more likely to lead to success, it raises some concerns about the sustainability of *IoT@schools* and the extent to which it can become a part of everyday classroom activity. School P2 took a slightly less selective approach, whilst aware of the need to have a pilot phase before implementing the project across the school and suggested ‘Always start small. Start with one or two classes for the project first and see how the project develops.’ (Head of Dept. School P2)

The secondary schools adopted a similar approach, but unlike School P2 their plans to scale up were not realised during the lifetime of the project. They suggested ‘Start with a pilot group of students... It helps us to solve problems and technical issues before rolling out to other levels.’(Principal, School S2). However, whilst restricting such an initiative to relatively small groups of highly motivated pupils may lead to demonstrable learning enhancement, it provides limited evidence of the potential for IoT-related activities to make an impact on inquiry-based approaches to science and geography throughout Singapore.

Robust technical infrastructure

Teacher interviews suggest that IoT is best used within contexts where there is robust technical infrastructure; since some expressed a degree of frustration at the limitations of technical infrastructure to make data available when they were needed, in an easily-accessible form. Examples included

> Sometimes devices or data could not be loaded on time when we scheduled the kids to work with it… (Head of Dept., School P2)
>
> The main issue was the website breakdown. I have to teach the students to use the cache version instead of the current live version so that they can access the data from previous weeks. This has happened twice already (Teacher, School S3)

These issues with both the school-based sensors and IoT access were surprising given the high level of technical infrastructure in Singapore, suggesting that the technology may not yet be sufficiently mature to be used routinely in schools around the world without significant preparation by committed teachers to avoid problems:

> One of the things we learnt from the technical issues is we always have to test the data and sensors first before the lesson. (Teacher, BPSS)

It is clear that having a robust and intuitive technical infrastructure is a prerequisite to successful implementation of a project of this kind.

Carefully-planned time allocation

Another key contextual factor from teacher interviews in the success of IoT activities appeared to be the careful planning of time allocation:

> The biggest challenge is time. We have finite time and also have to deliver the existing curriculum… We needed to be very clear on what is the objective of the project before we started in order to realise the outcome we were looking at. (Vice-Principal, School P1)

The project was identified as particularly time-consuming because of some of the technical issues arising:

> Sometimes devices or data could not be loaded on time when we scheduled the kids to work with it (Head of Dept. School P2)
>
> Subsequently, some things needed trial and error to test whether it would work, it also needed time (Vice Principal School S1).

Allocating time to teaching staff was identified as a precursor for success:

> You may need to offload the teachers involved from some of their work if they need time to execute the project. It does take up quite a bit of time. (Vice-Principal, School S1)

Another strategy employed was to limit the curriculum focus of the activities:

> We only decided to focus on certain areas (for inquiry). This is because we only have five periods a week on Science. We need to ensure the time is maximised fully. (Teacher, School P1)

Curriculum time allocation for science appears to be relatively generous in School P1, particularly by comparison with England, where one lesson per week would be more common, thus necessitating further limiting of focus. In Singapore, timing of examinations was felt to be a particular constraint; however there was a recognition that by spacing the project activities more evenly across the year this could be overcome:

> Currently what we are doing is mostly after exams. If were to do it again, we would pace it out, or do it on alternate weeks etc. (Teacher, School P1)

One school reported that it had made use of extra-curricular time to facilitate the student-directed learning required, but that with careful planning this could be avoided in future:

> To have them do self-directed learning is not easy as it takes up a lot of time including Saturdays. We do not much have time in the standard curriculum set aside for this as we need to teach them the standard fieldwork as well. The challenge next time would be how to best integrate everything together seamlessly into one whole package in which the students can be given time to work on this rather than having to stay back after school till 6pm for this project (Teacher, School S3).

Another strategy identified by the secondary schools was to run *IoT@schools* activities in longer lesson times, which would require amendments to the school timetable:

> We would want to try and see if we can run the sessions longer. Now there is only 1.5 hours and two hours per session. By the time the students come out with the hypothesis and possible ways to carry out the study, they don’t really have much time

> to analyse and come out with conclusions for what they need to prove. We probably need to plan out longer sessions with sequences (Teacher, SSS).

Again, these lesson durations appear relatively generous by UK standards, suggesting that inquiry-based pedagogy involving sensors and IoT may require re-structuring the school day, making it less likely to be adopted widely.

Related to the contextual factor of time allocation is that of compatibility with existing curricula, which although espousing inquiry-based approaches was felt to impose restrictions which might limit uptake:

> You also have to find out how can the project be well-integrated into the existing curriculum. This helps the teacher to not view it as an add-on to their workload. There are a lot of things to juggle in school already. A good integration can also support and enrich the learning of science. (Vice-Principal, School P1)

In secondary schools, the statutory geography curriculum was seen as limiting the age groups and time frames within which the project could be implemented, in order to fit with scheduled topic coverage:

> We want this to be a yearly project. Especially in term three, where the Sec 3s are covering weather and climate, they will be using this much more in detail (Teacher, S2)

Although the constraints of statutory curricula are a potential barrier to the success of such projects, it is possible for sufficiently motivated schools to achieve a balance between compliance with content coverage (including features such as the Singapore ‘Applied

Learning Programme’) and approaches which embody the espoused inquiry-orientation of the curriculum as a whole.

Given the curricular and timing constraints referred to above, contexts in which careful planning is undertaken appear more likely to maximise the potential of sensor technology to enhance student learning:

> We needed to be very clear on what is the objective of the project before we started in order to realise the outcome we were looking at (Vice-Principal, School P1)

The need to plan projects of this kind around the needs and interests of pupils is key to their success. A shift in the approach to lesson planning can be evidenced from examples uploaded to *Huddle* by School S2 and reflected upon as follows:

> When we develop the lesson designs, we have to move away from lessons based on traditional field work techniques. The design of the lessons have to change. We factored this into our future projects (Teacher, School S2)

Schools where there already exist consistent approaches to curriculum planning are at an advantage in taking on initiatives such as *IoT@Schools.* These depend on both the strength of leadership and pedagogical expertise of teachers.

Leadership and expertise needed to help accelerate investigative and inquiry-based learning

Interviewees stressed the need for school leaders to be involved in supporting the teaching teams undertaking the project:

> It is very important for school leaders to provide support. You may need to offload the teachers involved from some of their work if they need time to execute the project. (Vice-Principal, School P1)

In School P2, the Principal delegated all of the leadership of the project to the Head of Department, who was involved in the setting-up and monitoring of the project:

> We selected the teachers and classes which are involved in the project. After that the teachers discussed on their own and started the project. (Head of Dept, School P2)

Some of the secondary school leadership appears to have taken a more ‘hands-off’ approach to managing the project – handing it over to the teachers and playing a predominantly monitoring role:

> Trust that the teachers will pick it up, find their own way, and be supported for the project. I had a very good team and they know that they can come to me if they need advice (Principal, School S2).

Our observations of joint planning workshops and group interviews suggest that school leadership was a major factor in determining project success; those schools in which leaders engaged closely with the project were those with the best outcomes. A sense of teacher accountability to a leadership team with demonstrable commitment to the project was key to sustaining momentum.

School leaders identified the expertise of the participating teachers as significant to the success of such projects, including their enthusiasm, knowledge and leadership potential:

> Find a teacher that is excited about it. The passion of the teachers counts. (Principal, School P2)

> The teachers involved also need to have a certain extent of knowledge and skillsets in order to facilitate this project. (Vice-Principal, School P1)

The need to develop teachers’ expertise to be able to carry out the project effectively was identified by one secondary school leader:

> We started off with building the teachers’ capacity. This is key because if the teachers don’t know the technology well enough, they can’t teach the students (Vice-Principal, School S1)

Teachers themselves felt that they needed considerable technical expertise in order to support students when they encountered difficulties:

> The technical aspect and hardware know-how was also a challenge. The students don’t have much understanding of data loggers. The setting up of equipment requires a lot of explanation from the teachers as well as to give them the background around the set-up. Teachers do also meet challenges like the calibration of sensors. We also did some testing to ensure that the sensor was calibrated properly, but the data collected for a particular sensor at one-time was very haphazard. So the data then was not reliable. We had to spend time to test it out first. (Teacher, School P1)

Teachers also recognized the need for pedagogic expertise in order to set appropriate tasks for students, who were in some schools not yet ready to plan their own inquiry:

> Currently the teachers are the ones who come out with the experiments and use the data to teach the students on analysis and interpretation. (Teacher, School P1)

In those cases where pedagogical support offered through the project was taken up by participant teachers, the classroom activities were particularly effective. Occasionally teachers, perhaps due to time constraints, relied more on their own experience and therefore did not draw so much on outside sources of expertise:

> In some cases we feel that the schools could have benefitted from more interaction with our expertise to enhance their activities further. We appreciate that teachers have many demands on their time and so in some cases we feel that with more time available they could have benefitted in working with us more to set objectives and potential outcomes. (Project leader)

Teachers did acknowledge that their pedagogic expertise had developed through the project and that this had brought about changes in their classroom practice towards a wider repertoire of teaching strategies:

> The main forms of scaffolding we provided were in terms of guiding questions. We also picked out sections of the data to get them used to making sense of it first. We got them to observe the locations of the sensors and speculate which data set belongs to which sensors as they observed the data (Teacher, School S2).

Another important factor was the expertise of the students themselves, which some teachers drew upon for peer instruction:

> Having a facilitator (a pupil who had experience of *IoT@Schools* activities in the pilot phase) there to teach the next batch on how to use (the sensors), collect data, set up the weather station and analyse the data (Teacher, School S3)

Recognising and drawing upon this pupil expertise was seen as itself demanding a radical change in teachers’ pedagogy:

> It required more courage from us (the teachers) to hand over the teaching to the students and let them do peer mentoring (Teacher, School S3).

Discussion

Our findings suggest that several types of expertise are necessary for success in a project of this nature: teachers’ technical and pedagogical expertise and pupils’ technical expertise. These are linked since teachers need to develop pedagogical expertise to allow students to take the lead in supporting peer learning. Pierson (2014) observed that differences in new technology use by teachers were associated with individual levels of pedagogical expertise, which (Hennesy et al. (2007) suggest is adapted to the constraints imposed and the affordances offered when educational technologies are introduced. Chapman et al. (2010) found differences between teachers’ and pupils’ technical expertise in different types of school, however this is not borne out in our findings – perhaps because of the relative homogeneity of our sample – where primary teachers reported similar levels of technical expertise to their secondary counterparts.

Despite statutory curriculum change and Ministry of Education exhortations to adopt inquiry-based approaches to science and geography teaching and learning (MoE 2007, 2014) the *IoT@Schools* project teachers appeared relatively inexperienced in the management of such activities using sensor technology, suggesting that the pedagogic deconstruction and reconstruction process documented by Zhang et al. (2010) is still ongoing in Singapore. There is some evidence from our findings that pupil performance was enhanced by the use of this type of mobile technology within authentic scientific and geographical inquiry, as found by Daner et al. (2016) and Fernandez (2017), who asserts that the Internet of Things, applied as a tool to support the teaching process, improves student academic performance. Gomez et al. (2013) add that the learning potential of IoT is enhanced when combined with the use of ‘real objects’ (in our case, the data-loggers and sensors the students set up for themselves around their schools). However, the selection of relatively small, motivated sub-sets of the pupil population in the project schools limits the scope of these findings and the technical challenges experienced by the teachers clearly discouraged them from extending the approach to a wider ability range. The teachers’ comments on the support they needed to give pupils to make sense of the data from IoT sources, together with the constraints of time allocation, technical infrastructure and curriculum compliance (Lipponen (1999) suggest that they experienced many of the conflicts inherent in inquiry-based approaches between teacher- and student-centredness, content and process, and curriculum and assessment found by Kim et al. (2013). The affordances of drawing upon multiple remote data sources from the IoT in motivating pupils to undertake their own inquiries and become more sophisticated in their selection and analysis of data reported by Chatterjea et al. (2008) were realized to an extent in the *IoT@Schools* project, however they experienced unanticipated difficulties in accessing and translating IoT data into a form they could understand, suggesting that significant preparatory work is required and that a common protocol or format for IoT data is needed to make them more useful for educational purposes.

Conclusion

The Internet of Things is a rapidly-developing network of sensors, data-collection and controllable devices which will play an increasing role in everyday life as people become used to the affordances of monitoring and controlling many of their domestic appliances and systems remotely. To this extent, familiarization with the IoT will benefit pupils in their future careers and roles as citizens, however its full educational potential is yet to be realized, as demonstrated by the scarcity of references in the educational literature. The *IoT@Schools* project sought to drive pedagogic change towards more inquiry-based approaches to science and technology education through use of IoT data sources with those collected by pupils to enhance their data literacy. This aim has been achieved to an extent through a series of small pilots in five schools, however the pedagogic and technical challenges associated with using this technology as part of everyday classroom practice proved too great to fully embed the approaches in the short time available. More robust technical infrastructure, easily accessible and comprehensible data sources and significant professional development for teachers is required to make inquiry-based learning with enhanced data literacy a reality for pupils in Singapore and elsewhere.

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Appendix 1A: Online student pre and post-project attitude survey

For each statement, please click the button that matches your opinion.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
1. I investigate in science/geography					
2. I use technology in science/geography					
3. I collect data in science/geography					
4. I learn facts in science/geography					
5. I find things out in science/geography					
6. My teacher gives me interesting things to do					
7. I am interested in what my teacher says					
8. My teacher is easy to understand					
9. I think of things not related to the lesson					
10. I know what the teacher expects me to do					

Appendix 1B: Online student post-project evaluation survey

For each statement, please click the button that matches your opinion.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
1. I have enjoyed the IoT@School project					
2. The activities we have done as part of the IoT@School project have been interesting					
3. The activities have been challenging					
4. I now know more about the Internet of Things than I knew at the beginning of the project					
5. I know more about how to set up sensors to measure things					
6. I have got better at problem-solving					
7. I have got better at planning an investigation using sensors					
8. I have got better at finding and using sensor data from the internet					

Appendix 2A: Semi-structured teacher focus group pre-project interview schedule

1. Please tell me about your school
2. What is the IT infrastructure in the school?
3. What types of ICT do you find most useful in science/geography?
4. Are students able to bring their own ICT equipment into school?
5. How did you come to be a part of this project?
6. Which students are involved in this project?
7. What equipment have you been given to carry out this project?
8. Have you been given any other support to do the project?
9. Is there any other support you think you will need?
10. Are students going to be using the IoT@schools website to compare data internationally?

Appendix 2B: Semi-structured teacher focus group post-project interview schedule

1. What were the highlights of the IoT@schools project?
2. Which classroom activities have worked best and why?
3. Have there been any activities that has been more challenging or not work as well as you have hoped?
4. If you would have to run those activities again, what would you do differently next time?
5. How does running these activities involve making any changes in your own teaching approach?
6. How has running these activities involve you or your students take a more investigative or problem solving approach towards geography?
7. What are the main things that your students have learnt through the project eg. The internet of things, sensors, problem solving strategies etc.
8. Any other things you want to say about the project?

Appendix 3: Semi-Structured interview with senior managers post-project

1. What were the highlights of the IoT@schools Project?
2. What approach have you taken to manage the project?
3. What kinds of expertise have been needed to run the project successfully?
3. What are the main challenges for you as a school leader in terms of the project?
4. What advice would you give to other school leaders wanting to run such project?
5. Any other comments?